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HYPOHYDRATION AND EXERCISE: EFFECTS OF GENDER, ENVIRONMENT AND --ETC(U)
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HYPOHYDRATION AND EXERCISE:
EFFECTS OF GENDER, ENVIRONMENT AND HEAT ACCLIMATION

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Abbreviated Title: Hypohydration and Exercise

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ABSTRACT

The purpose of this study was to examine the effects of heat acclimation and subject gender on treadmill exercise in a comfortable (20°C, 40% rh), a hot-dry (49°C, 20% rh) and a hot-wet (35°C, 79% rh) environment while subjects were hypo- or euhydrated. Six male and six female subjects, matched for maximal aerobic power and percent body fat, attempted two exercise tests in each environment both before and after a 10-day heat acclimation program. One exercise test was attempted when euhydrated and the other test when hypohydrated (-5.0% from baseline body weight). In general, no significant ($P > 0.05$) differences were noted between men and women at the completion of exercise for rectal temperature (T_{re}), mean skin temperature ($\bar{T}_{sk}$) or heart rate (HR) during any of the experimental conditions. Hypohydration was generally found to increase T_{re} and HR responses as well as to decrease sweat rate values while not altering $\bar{T}_{sk}$ responses. In the hypohydration experiments, heat acclimation significantly reduced T_{re} (0.19°C) and HR ($13\ b \cdot min^{-1}$) responses in the comfortable environment, but reduced only HR responses in the hot-dry ($21\ b \cdot min^{-1}$) and hot-wet ($21\ b \cdot min^{-1}$) environments. The present findings indicate that men and women respond in a physiologically similar manner to hypohydration during exercise. It is also suggested that an expanded plasma volume, mediated by heat acclimation, may have attenuated T_{re} and HR responses during hypohydration.

Index Terms

climate; dehydration; euhydration; heart rate; heat acclimatization; heat stress; mean skin temperature; plasma volume; rectal temperature; sex differences; sweat loss; temperature regulation

INTRODUCTION

Exercise performance in a hot environment has been shown to be primarily affected by aerobic fitness (22), state of acclimation (21), and level of hydration (18). Both the singular and interactive effects of aerobic fitness and state of acclimation have previously been described in detail (12,22). Numerous investigations have also examined the effect of hypohydration on physiological responses to exercise in the heat (4,18,20,29). These investigations have demonstrated that in comparison to euhydration, hypohydration results in an increased heart rate and core temperature during exercise. The increased heart rate has been associated with a decreased ventricular filling pressure and stroke volume (20,31), whereas elevated core temperature has been associated with a decreased sweat rate response (9,19) and decreased cutaneous blood flow (4,8,20). Previous investigations have not considered the interactive effect of hypohydration and state of acclimation during exercise in the heat. Buskirk et al. (3) addressed this question, but used a moderate (26°C) test environment. These scientists reported that heat acclimation did not alter rectal temperature response to exercise when hypohydrated, and recommended additional research into this area.

Relatively few investigations have examined the effects of hypohydration on females during exercise in a hot (5,7,25) or a comfortable (15) environment. In fact, direct comparisons between the genders for physiological responses to hypohydration during exercise have been performed on a total of six subjects unmatched for maximal aerobic power (5,7). In order to examine possible gender differences during exercise in the heat, the subject populations should be matched for maximal aerobic power. Previous investigations have indicated that when genders are matched for maximal aerobic power, many of the reported physiological differences during exercise in the heat become less pronounced

(1,11,16,27). In addition, Shapiro et al. (27) have reported that in a matched population performing treadmill exercise the men have a physiological advantage in a hot-dry environment and the women have a physiological advantage in a hot-wet environment.

The purpose of the present investigation was to examine the effects of heat acclimation and subject gender on physiological responses to exercise during hypohydration. These factors were examined in a comfortable, a hot-dry and a hot-wet environment in a group of men and women matched for maximal aerobic power and percent body fat.

METHODS

Subjects. Six male and six female volunteers participated in this investigation. The men had a mean (±SD) age of 24 ± 3 years, height of 167.9 ± 5.5 cm, and weight of 75.5 ± 8.3 kg. The women had a mean (±SD) age of 26 ± 3 years, height of 161.2 ± 6.2 cm, and weight of 57.7 ± 8.4 kg. Before the initial test session, subjects were informed of the purpose and potential risks of the study, the extent of their involvement, and their right to terminate participation at will. Each expressed understanding by signing a statement of informed consent.

Protocol. All testing was conducted in Natick, Massachusetts during the late winter and early spring months (January - April) when subjects were naturally unacclimated to heat. Prior to experimental testing, each subject's percent body fat was determined by underwater weighing and maximal aerobic power was determined by a treadmill running test. The maximal protocol was progressive in intensity but discontinuous in nature. The initial treadmill grade was zero, and the grade was increased by 2.5% increments for each additional exercise bout.

Exercise bouts consisted of running (2.68 or 3.13 m • s^{-1}) for 2.5-minute intervals with a subsequent 10-minute rest period. Each subject's running velocity was determined from his or her heart rate response to a 10-minute warm-up walk (1.56 m • s^{-1} at 10% grade). If the elicited heart rate response equaled or was greater than 145 b • min^{-1}, the 2.68 m • s^{-1} velocity was employed for the maximal test. Established criteria were employed for determination of peak $\dot{V}O_2$ for the 2.68 m • s^{-1} (17) and 3.13 m • s^{-1} (30) tests. In addition, during the three weeks prior to the first heat exposure and throughout the study, nude body weights were measured in the morning after voiding before breakfast. These daily body weights were used to establish baseline body weights.

Subjects attempted to complete two experimental tests in a hot-wet (T_a = 35°C, rh = 79%), hot-dry (T_a = 49°C, rh = 20%), and comfortable (T_a = 20°C, rh = 40%) environment; once when euhydrated and once when hypohydrated. These six experimental tests were repeated both before and after heat acclimation. During the pre-acclimation period, subjects were exposed to heat only one time per week to diminish the effects of acclimation. Each of these experimental tests was 140 minutes (4 repeats of 10 min rest, 25 min exercise) unless terminated by predetermined end-points of a heart rate greater than 180 b • min^{-1} or rectal temperature greater than 39.5°C. During exercise, subjects walked on a level treadmill at 1.34 m • s^{-1}, and during the rest periods subjects were weighed and rehydrated with tap water to maintain desired body weight (either baseline or -5.0% from baseline).

Approximately 24 hours prior to the hypohydration tests, subjects initiated a program of voluntary dehydration. Also on the afternoon prior to the hypohydration tests, subjects performed light exercise in a hot (T_a = 38°C, rh = 20%) environment to dehydrate to their target body weight (-5.0% from baseline). After achieving target body weight, subjects were removed to a

comfortable environment to spend the night under supervision. The following morning subjects were awakened (0600 h), provided with a light breakfast and tested (0800 h). The euhydration experimental tests were conducted at 1030 h.

The men and women were concurrently acclimated for 10 consecutive days by walking on a level treadmill at 1.34 $m \cdot s^{-1}$ for two 50-minute exercise bouts that were spaced by a 10-minute rest period. During this acclimation program the environmental conditions of hot-wet and hot-dry were alternated. All testing was conducted with the subjects wearing shorts, T-shirts and tennis shoes; ad libitum water drinking was encouraged during the acclimation sessions.

Physiological Variables. Electrocardiograms were obtained with chest electrodes (CM5 placement) and radio telemetered to an oscilloscope-cardiotachometer unit (Hewlett-Packard). Oxygen uptake ($\dot{V}O_2$, $l \cdot min^{-1}$ STPD) was determined by open circuit spirometry. Subjects breathed via a two-way breathing valve (Collins single J) and expired gases were collected in 100-liter Douglas bags. Expired gases were analyzed for O_2 and CO_2 concentrations with an electrochemical O_2 analyzer (Applied Electrochemistry S-3 A) and an infrared CO_2 analyzer (Beckman LB-2), respectively. The volume of expired air was measured by a Tissot gasometer.

During each experimental test, rectal temperature was recorded from a Yellow Springs Instrument rectal thermistor probe inserted ~ 10 cm beyond the anal sphincter. Skin temperatures were monitored with a three-point thermocouple skin harness (chest, calf and forearm) and mean weighted skin temperature was calculated (2). Both rectal temperature and mean skin temperature values were plotted for each subject at 2-minute intervals using a HP 9825-A computer and HP 9862-A plotter. Body weights were determined on a K-120 Sauter precision electronic balance (accuracy ± 10 g). Sweat rates

($\dot{m}_{sw}$) were calculated by nude body weight loss adjusted for water intake and urine output.

Venous blood samples (5 ml) were obtained prior to each experimental test session after the subjects stood for 20 minutes in an antechamber ($T_a = 20^{\circ}C$, rh = 30%). Triplicate determinations were made of hematocrit and duplicate determinations were made of hemoglobin (Hycel, cat. # 116C). Plasma osmolality was determined by freezing point depression (Precision Systems Inc., Osmette A). The relative percent change in plasma volume was calculated from appropriate hemoglobin and hematocrit values (6).

Statistical Analysis. Means, standard deviations, and independent and paired t tests were performed on a programmable calculator (Hewlett-Packard 85). The Bonferroni correction method was employed when repeated t tests were performed (13). Statistical significance was accepted at the $P < 0.05$ level.

RESULTS

Table 1 provides a description of the male and female subjects. The women had a significantly ($P < 0.05$) lower A_D and a higher $A_D \cdot wt^{-1}$ ratio. However, no significant differences were found between the groups for percent body fat or maximal aerobic power. During the experimental and acclimation sessions, subjects walked on a level treadmill at $1.34\ m \cdot s^{-1}$ which elicited an oxygen uptake response of $13.5\ ml \cdot kg^{-1} \cdot min^{-1}$ (28% peak $\dot{V}O_2$) and $13.4\ ml \cdot kg^{-1} \cdot min^{-1}$ (30% peak $\dot{V}O_2$) for the men and women, respectively. The heat acclimation program decreased ($P < 0.05$) mean final heart rate (HR) by 19 $b \cdot min^{-1}$ and $8\ b \cdot min^{-1}$ during exercise in the hot-dry and hot-wet environments, respectively. In addition, mean final rectal temperature (T_{re})

decreased ($P < 0.05$) by 0.15°C and 0.20°C during exercise in the hot-dry and hot-wet environments, respectively. Physiological acclimation was demonstrated by nonsignificant differences in physiological responses (HR and T_{re}) between the last two acclimation days of each environmental condition for both genders.

TABLE 1 ABOUT HERE

Table 2 presents data on decreases from baseline body weight for the hypohydration experiments. Clearly, the subjects were very close to the -5.0% target weight. During the euhydration experiments, the subjects were a mean of 0.6% below baseline body weight and had a maximum deviation of -1.0%. No significant differences were found between pre- and post-acclimation weights for either the eu- or the hypohydration experiments. Hypohydration was found to significantly ($P < 0.05$) increase plasma osmolality values during the pre-acclimation (from 281 ± 4 to 290 ± 4 mosmol • kg^{-1}) and the post-acclimation (from 281 ± 4 to 289 ± 5 mosmol • kg^{-1}) tests. Plasma osmolality values were not significantly different between the pre- and post-acclimation tests during either the eu- or the hypohydration experiments. During the hypohydration experiments, plasma volume was decreased by 11% and 5% for the pre- and post-acclimation tests, respectively. These reductions in plasma volume were not significantly ($P > 0.05$) different between pre- and post-acclimation tests.

TABLE 2 ABOUT HERE

Gender effect. Figures 1 through 4 present the male and female subjects' physiological responses during exercise in the three environmental conditions. Table 3 summarizes the results of the statistical analyses to examine possible

gender differences. In general, significant differences were not found between the genders for T_{re}, final mean skin temperature ($\bar{T}_{sk}$) or HR responses during exercise in each of the conditions. However, the women had a higher (15 $b \cdot min^{-1}$, $P < 0.05$) HR response post-acclimation when euhydrated in the hot-dry environment. The women were also found to have lower (65 $g \cdot m^{-2} \cdot h^{-1}$; $P < 0.05$) $\dot{m}_{sw}$ values pre-acclimation when hypohydrated in the hot-dry environment. In the hot-wet environment, the women were found to have lower $\dot{m}_{sw}$ values during pre-acclimation when euhydrated (72 $g \cdot m^{-2} \cdot h^{-1}$; $P < 0.05$) and hypohydrated (104 $g \cdot m^{-2} \cdot h^{-1}$; $P < 0.01$) as well as during post-acclimation when euhydrated (145 $g \cdot m^{-2} \cdot h^{-1}$; $P < 0.01$) and hypohydrated (133 $g \cdot m^{-2} \cdot h^{-1}$; $P < 0.01$).

TABLE 3 AND FIGURES 1 THROUGH 4 ABOUT HERE

When gender differences were not established for a particular response, the data were combined for subsequent statistical analyses comparing the eu- to hypohydration responses and the pre- to post-acclimation responses. In all cases when separate analyses were performed for men and women similar results were obtained. Therefore, Tables 4 and 5 present a summary of the statistical analyses for the combined groups.

Comfortable environment. Tables 4 and 5 summarize the results of the statistical analyses comparing the eu- to hypohydration experiments and the pre- to post-acclimation tests, respectively. Hypohydration increased ($P < 0.05$) T_{re} responses by 0.30°C above euhydration levels during the pre-acclimation test; however, post-acclimation there were no differences between the two hydration states. Heat acclimation did not alter T_{re} responses during the euhydration experiments; but heat acclimation decreased ($P < 0.05$) T_{re} responses by 0.19°C

during the hypohydration experiments. Hypohydration increased ($P < 0.05$) $\bar{T}_{sk}$ by 1.57°C during the pre-acclimation test; however, post-acclimation, no differences in $\bar{T}_{sk}$ were observed between the two hydration states. Heat acclimation did not alter $\bar{T}_{sk}$ responses in either the eu- or the hypohydration experiments. Hypohydration decreased ($P < 0.01$) $\dot{m}_{sw}$ values by 33 $g \cdot m^{-2} \cdot h^{-1}$ and 67 $g \cdot m^{-2} \cdot h$ during the pre- and post-acclimation tests, respectively. Heat acclimation did not alter $\dot{m}_{sw}$ values in either the eu- or the hypohydration experiments. Hypohydration increased ($P < 0.01$) HR responses by 19 $b \cdot min^{-1}$ above euhydration levels during the pre-acclimation tests; however, post-acclimation there were no differences observed. Heat acclimation did not alter HR responses during the euhydration experiments; but heat acclimation decreased ($P < 0.01$) HR by 13 $b \cdot min^{-1}$ during the hypohydration experiments.

TABLES 4 AND 5 ABOUT HERE

Hot-dry environment. Hypohydration increased T_{re} responses by 0.46°C ($P < 0.05$) and 0.83°C ($P < 0.01$) above euhydration levels during the pre- and post-acclimation tests, respectively. Heat acclimation decreased ($P < 0.01$) T_{re} responses by 0.24°C during the euhydration experiments, but did not alter T_{re} responses during the hypohydration experiments. The $\bar{T}_{sk}$ responses were not altered by level of hydration or state of acclimation. Hypohydration reduced ($P < 0.01$) $\dot{m}_{sw}$ values by 65 $g \cdot m^{-2} \cdot h^{-1}$ during the pre-acclimation test; post-acclimation no differences in $\dot{m}_{sw}$ values were observed between the two hydration states. Heat acclimation did not alter $\dot{m}_{sw}$ values in either the eu- or the hypohydration experiments. Hypohydration increased HR responses by 13 $b \cdot min^{-1}$ ($P < 0.10$) and 16 $b \cdot min^{-1}$ ($P < 0.01$) during the pre- and post-acclimation tests, respectively. Heat acclimation decreased HR responses by 24

$b \cdot min^{-1}$ ($P < 0.01$) and 21 $b \cdot min^{-1}$ ($P < 0.01$) during the eu- and hypohydration experiments, respectively.

Hot-wet environment. Hypohydration increased T_{re} responses by 0.46°C ($P < 0.05$) and 0.54°C ($P < 0.01$) above euhydration levels during the pre- and post-acclimation tests, respectively. Heat acclimation decreased ($P < 0.05$) T_{re} responses by 0.25°C during the euhydration experiments; but heat acclimation did not alter T_{re} responses during the hypohydration experiments. The $\bar{T}_{sk}$ responses were not altered by level of hydration or state of acclimation. No differences in $\dot{m}_{sw}$ values were observed between the two hydration states during the pre-acclimation test. However, hypohydration decreased ($P < 0.01$) $\dot{m}_{sw}$ values by 102 $g \cdot m^{-2} \cdot h^{-1}$ during the post-acclimation test. Heat acclimation increased ($P < 0.01$) $\dot{m}_{sw}$ values by 101 $g \cdot m^{-2} \cdot h^{-1}$ for the euhydration experiments, but did not alter $\dot{m}_{sw}$ values for the hypohydration experiments. Hypohydration increased ($P < 0.05$) HR responses by 19 $b \cdot min^{-1}$ during the pre-acclimation test, but post-acclimation did not alter HR responses. Heat acclimation decreased HR responses by 9 $b \cdot min^{-1}$ ($P < 0.05$) and 21 $b \cdot min^{-1}$ ($P < 0.01$) during the eu- and hypohydration experiments, respectively.

DISCUSSION

The increased core temperature during hypohydration has been attributed to both a plasma hyperosmolality (10) and a plasma hypovolemia (8,9,10) contributing to a decreased sweat rate response and decreased cutaneous blood flow. Diuretics have been shown to result in an iso-osmotic hypovolemia (4,9,20) and therefore were not used to dehydrate our subjects. The present investigation employed a combination of voluntary dehydration, with physical exercise and heat stress to achieve the desired level of hypohydration. These methods

resulted in a hyperosmotic hypovolemia for the hypohydration experiments. One methodological consideration of this investigation was to achieve the desired level of hypohydration without large changes in body weight from the beginning to end of the study. As a result the subjects did not initiate a program of voluntary dehydration until approximately 24 h prior to each hypohydration test. This insured a decrease in the volume of body water without a concomitant reduction in adipose and/or lean body mass. In fact, the subjects had a maximal change in baseline body weight of 0.8 kg during the duration of the investigation. Another methodological consideration was to avoid partial heat acclimation from the pre-acclimation dehydration sessions. During the pre-acclimation experiments the subjects completed only one hypohydration experiment per week. Therefore, any partial acclimation would have been minimal and consistent between subjects.

To our knowledge, research has not previously been reported that directly examined the influence of gender on the hypohydration response to exercise. The present data indicated that physiological differences between the genders were not systematically altered by level of hydration. The elicited T_{re} and $\bar{T}_{sk}$ responses were similar for both genders during exercise in each of the studied conditions. In addition, similar $\dot{m}_{sw}$ values were found for both genders in the comfortable and hot-dry environments. In the hot-wet environment, women had significantly lower $\dot{m}_{sw}$ values than men when eu- and hypohydrated both before and after heat acclimation. The limited evaporative capacity (E_{max}) of the hot-wet environment resulted in nonevaporated sweat and wetted skin. Previous investigations have suggested that women have an increased sensitivity to wetted skin which causes greater sweat suppression in a hot-wet environment (1,27). Our data indicated that neither hydration level nor acclimation state changed this increased sensitivity to wetted skin in women.

Despite having significantly lower $\dot{m}_{sw}$ values, the women had similar T_{re} responses in the hot-wet environment. It is possible that the lowered $\dot{m}_{sw}$ values in women were from a decreased unevaporated sweat with no change in evaporated sweat (1). However, if evaporative heat loss was less in women then the radiation and convection (R+C) component of the heat balance equation would need to have increased proportionally to enable the same core temperature. Heat exchange by R + C is related to the surface area available to dissipate metabolic heat. In comparison to the men, the women had a 14% larger $A_D \cdot wt^{-1}$ which should have enabled compensatory heat loss by R + C (27,28). A combination of greater sweat suppression and a larger $A_D \cdot wt^{-1}$ should enable women to resist dehydration in hot-wet environments. Teleologically, this may occur because women have a smaller blood volume (as well as a smaller total body water volume) than men; therefore, a given volume of sweat would result in a relatively greater plasma hypovolemia for women.

Heat acclimation significantly reduced T_{re} responses but did not alter $\dot{m}_{sw}$ values during hypohydration in the comfortable environment. During exercise in this environment, metabolic heat would be dissipated via evaporation (E) as well as by R + C. Since the comfortable environment had a high E_{max}, the secreted sweat should have been evaporated and the skin dry. Therefore, a reduced $\dot{m}_{sw}$ value during hypohydration would result in either greater heat storage or a compensation by R + C to dissipate the metabolic heat. Pre-acclimation the reduced $\dot{m}_{sw}$ values during hypohydration resulted in a greater heat storage as evidenced by the increased T_{re} responses. However, post-acclimation the reduced $\dot{m}_{sw}$ values did not result in altered T_{re} responses. After heat acclimation the subjects probably had an expanded plasma volume (26,31), and a larger blood volume for a given level of hydration. Shapiro _et al._ (26) have reported data suggesting that heat acclimation expanded blood volume during

exercise in a comfortable environment. This expanded blood volume could have resulted in an increased cutaneous blood flow for a given core temperature (8,20) and therefore enabled compensatory heat loss via R + C to dissipate metabolic heat. It might be expected that an increased cutaneous blood flow would increase $\bar{T}_{sk}$ values. However, we did not detect a change in $\bar{T}_{sk}$ values from pre- to post-acclimation.

Previous investigations conducted in hot environments have reported that hypohydration elicited elevated core temperature responses in conjunction with unchanged (4) or decreased (9,29) $\dot{m}_{sw}$ values during exercise. In agreement, we found hypohydration to elicit significantly higher T_{re} responses with either unchanged or decreased $\dot{m}_{sw}$ values. It should be noted, however, that while $\dot{m}_{sw}$ values were similar for some eu- and hypohydration experiments, the T_{re} responses were still significantly higher during hypohydration. Therefore, sweat rate would be lower for a given core timperature and the potential for heat dissipation via E is less (19). These findings are consistent with a recent paper indicating that hypovolemia results in a reduced slope (Δ sweat rate/Δ esophageal temperatuare) of the sweat rate response during exercise (9). During exercise in the hot environments, heat loss by R + C would be less able to compensate for the decreased E because of the relatively high ambient temperatures. Therefore, the decreased slope of the sweat rate response would result in increased T_{re} responses during exercise in the heat.

Hypohydration has been shown to elevate HR responses during exercise in comfortable (3,14) and hot (20,29) environments. These elevated HR responses are associated with a decreased blood volume which probably reduces ventricular filling pressure and stroke volume (20). As a result, HR increases in an attempt to maintain cardiac output during exercise. The present investigation found hypohydration to elicit higher HR responses than euhydration during the pre-

acclimation tests at all three environmental conditions. During the post-acclimation tests, however, hypohydration elicited higher HR responses only in the hot-dry environment. In fact, heat acclimation reduced HR responses during hypohydration in all three environmental conditions. The physiological mechanism responsible for the reduced HR responses after heat cllimation may be an expanded plasma volume. As noted previously, heat acclimation mediates and expanded plasma volume during exercise in comforatable (26) and hot (26,31) environments. A larger plasma volume post-acclimation, despite hypohydration, could improve ventricular filling thus mediating a larger stroke volume and lower HR (31). Two recent papers have shown that an acutely expanded blood (8) or plasma (24) volume will lower HR responses during exercise.

Buskirk et al. (3) have previously attempted to determine the effects of heat acclimation on physiological responses to exercise when hypohydrated in a moderate (26°C) test environment. Their subjects were tested when eu- and hypohydrated (-5.5% of body weight), both before and after a 3-week program of either heat acclimation, physical training, or no activity (sedentary control). They found that heat acclimation reduced HR responses during hypohydration, and that physical training reduced both HR and T_{re} responses during hypohydration. However, they reported that an increased metabolic rate during the post-acclimation test (from increased treadmill velocity) may have masked any reductions in T_{re} values. The present investigation found heat acclimation to reduce both HR and T_{re} values during the hypohydration experiments in the comfortable environment. It seems doubtful that a training effect would have contributed to our subjects' lowered responses, as their treadmill walks elicited only 30% of peak oxygen uptake. This relative exercise intensity, which is similar to that employed by other heat acclimation studies (1,11), is below the level believed necessary to elicit a training effect (23).

The present investigation's findings indicate that men and women respond in a physiologically similar manner to hypohydration during exercise. In addition, when subjects are hypohydrated during exercise, heat acclimation appears to decrease thermoregulatory and cardiovascular strain in a comfortable environment, but only decreased cardiovascular strain in hot environments. It seems that an expanded plasma volume, mediated by heat acclimation, could provide a physiological mechanism for reducing these strains.

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ACKNOWLEDGEMENTS

Recognition is due to the test subjects who made this study possible.

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Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

Table 1. Description of the men and women subjects.

		Surface Area (A_D) (m^2)	$A_D \cdot wt^{-1}$ (%)	Body Fat (%)	Maximal Aerobic Power ($ml \cdot kg^{-1} \cdot min^{-1}$)
Men (n = 6)	$\bar{X}$	1.85	2.46	20.0	47.9
	SD	0.12	0.14	4.8	4.0
	range	1.7-2.1	2.3-2.7	15-28	42-53
Women (n = 6)	$\bar{X}$	1.60*	2.80*	24.7	45.4
	SD	0.13	0.20	5.2	6.7
	range	1.5-1.8	2.6-3.1	19-33	40-55

*Women are significantly different from men at the $P < 0.05$ level

Table 2. Percent decreases from baseline body weight for the hypohydration experiments.

Condition		Men	Women	Combined
Comfortable				
pre-	$\bar{X}$	4.9	4.9	4.9
	SD	0.3	0.6	0.5
post-	$\bar{X}$	4.9	4.8	4.8
	SD	0.3	0.3	0.3
Hot-Dry				
pre-	$\bar{X}$	5.1	5.1	5.1
	SD	0.1	0.3	0.2
post-	$\bar{X}$	4.8	4.9	4.8
	SD	0.2	0.2	0.4
Hot-Wet				
pre-	$\bar{X}$	4.8	5.0	4.9
	SD	0.4	0.3	0.4
post-	$\bar{X}$	4.9	4.9	4.8
	SD	0.2	0.2	0.3

pre-, pre-acclimation; post-, post-acclimation

Table 3. Summary of the statistical analyses for gender differences in the eu- and hypohydration experiments.

	Comfortable		Hot-Dry		Hot-Wet	
	Eu.	Hypo.	Eu.	Hypo.	Eu.	Hypo.
Pre-Acclimation						
T_{re}	=	=	=	=	=	=
$\bar{T}_{sk}$	=	=	=	=	=	=
$\dot{m}_{sw}$	=	=	=	↓	↓	↓
HR	=	=	=	=	=	=
Post-Acclimation						
T_{re}	=	=	=	=	=	=
$\bar{T}_{sk}$	=	=	=	=	=	=
$\dot{m}_{sw}$	=	=	=	=	↓	↓
HR	=	=	↑	=	=	=

=, no difference; ↑ ,women greater than men; ↓ ,women less than men; T_{re}, rectal temperature; $\bar{T}_{sk}$, mean skin temperature; $\dot{m}_{sw}$, total body sweat rate; HR, heart rate

Table 4. Summary of the statistical analyses for comparison of the euhydration to the hypohydration experiments.

	Comfortable		Hot-Dry		Hot-Wet	
	Pre-	Post-	Pre-	Post-	Pre-	Post-
T_{re}	↑	=	↑	↑	↑	↑
$\bar{T}_{sk}$	↑	=	=	=	=	=
$\dot{m}_{sw}$	↓	↓	↓	=	=	↓
HR	↑	=	= or ↑	↑	↑	=

Pre-, pre-acclimation test; Post-, post-acclimation test; =, no difference; ↑, hypohydration response greater than the euhydration response; ↓, hypohydration response less than the euhydration response; T_{re}, rectal temperature; $\bar{T}_{sk}$, mean skin temperature; $\dot{m}_{sw}$, total body sweat rate; HR, heart rate

Table 5. Summary of the statistical analyses for comparison of the pre- to the post-acclimation experiments.

	Comfortable		Hot-Dry		Hot-Wet	
	Eu.	Hypo.	Eu.	Hypo.	Eu.	Hypo.
T_{re}	=	↓	↓	=	↓	=
$\bar{T}_{sk}$	=	=	=	=	=	=
$\dot{m}_{sw}$	=	=	=	=	↑	=
HR	=	↓	↓	↓	↓	↓

Eu., euhydration experiment; Hypo., hypohydration experiment; =, no difference; ↑, post-acclimation response greater than pre-acclimation; ↓, post-acclimation response less than pre-acclimation; T_{re}, rectal temperature; $\bar{T}_{sk}$, mean skin temperature; $\dot{m}_{sw}$, total body sweat rate; HR, heart rate

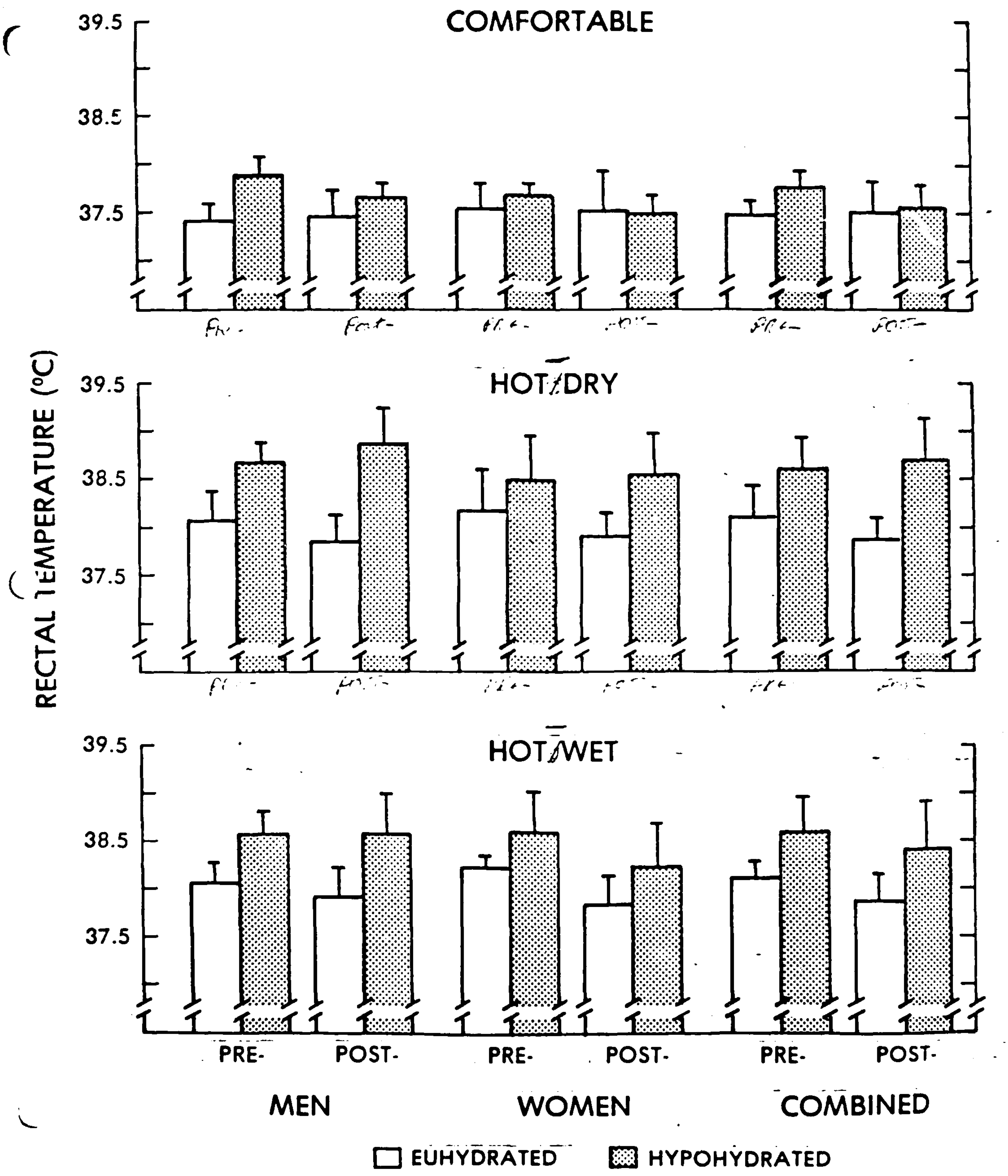
FIGURE LEGENDS

FIG. 1. Final exercise rectal temperature responses ($\bar{X}$ + SD) for the examined experimental conditions. Pre- is pre-acclimation and Post- is post-acclimation.

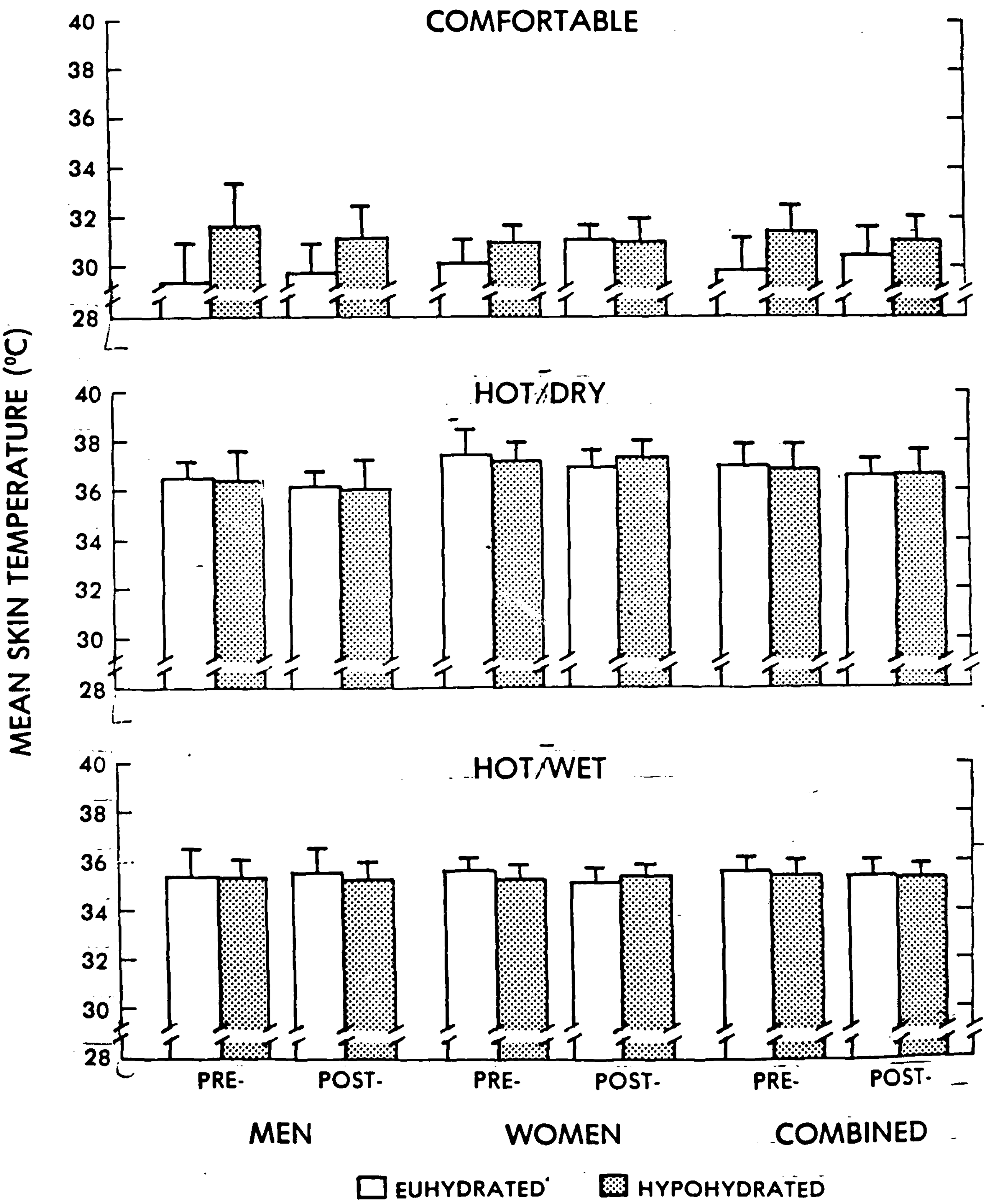
FIG. 2. Final exercise mean skin temperature responses ($\bar{X}$ + SD) for the examined experimental conditions. Pre- is pre-acclimation and Post- is post-acclimation.

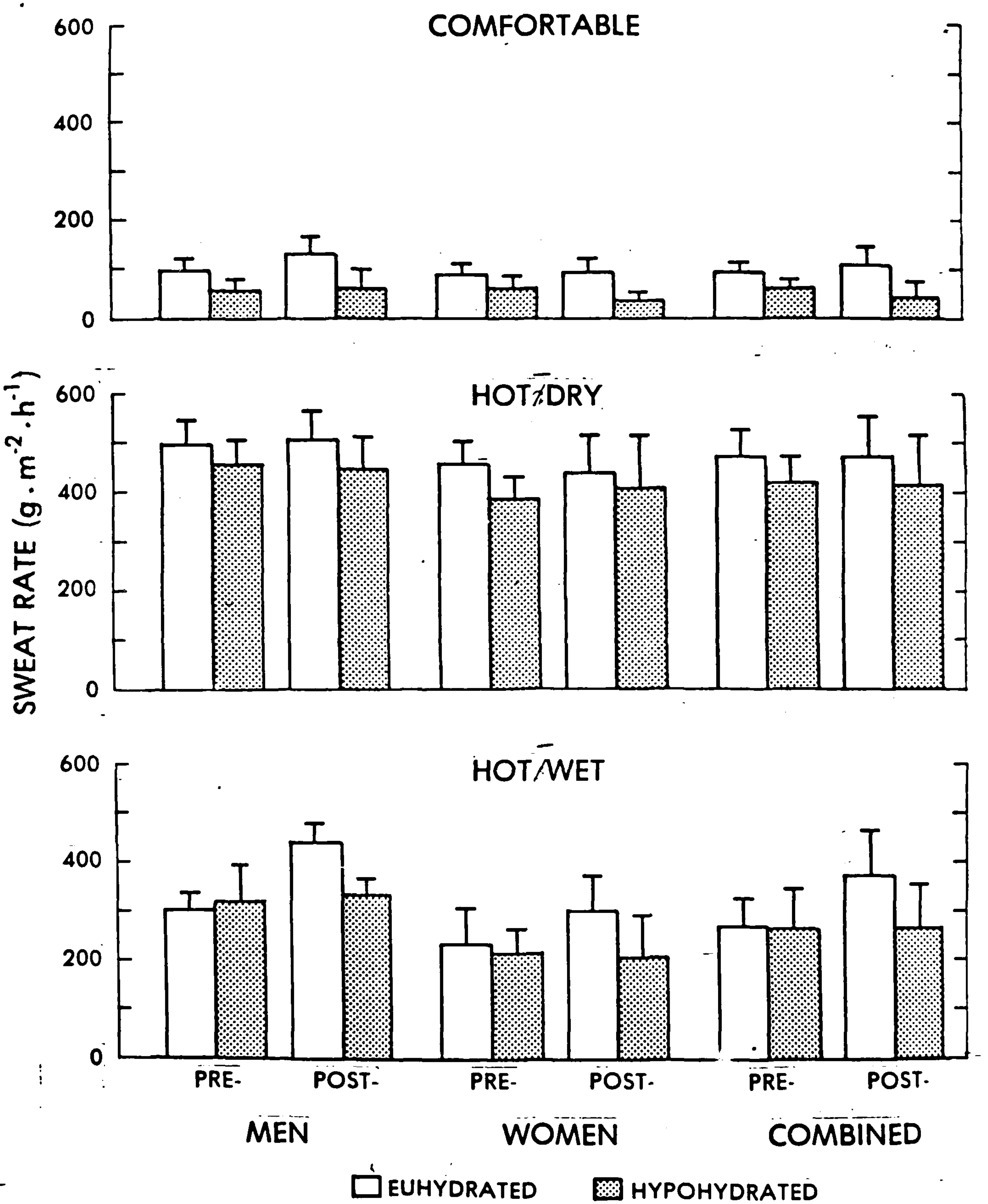
FIG. 3. Sweat rate values ($\bar{X}$ + SD) for the examined experimental conditions. Pre- is pre-acclimation and Post- is post-acclimation.

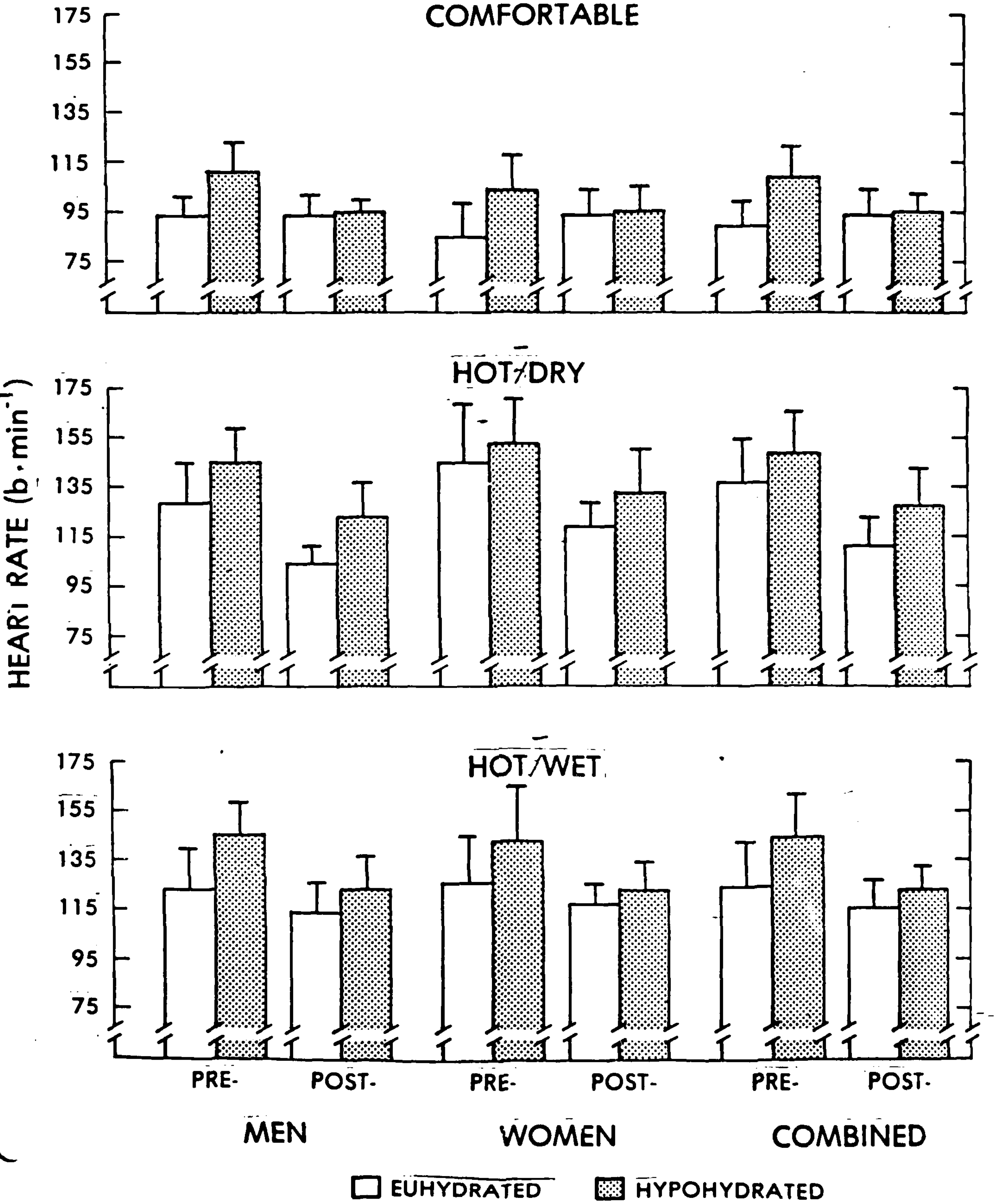
FIG. 4. Final exercise heart rate responses ($\bar{X}$ + SD) for the examined experimental conditions. Pre- is pre-acclimation and Post- is post-acclimation.



COMFORTABLE
HOT/DRY
HOT/WET
39.5
38.5
37.5
RECTAL TEMPERATURE (°C)
PRE-
POST-
PRE-
POST-
PRE-
POST-
MEN
WOMEN
COMBINED
EUHYDRATED
HYPOHYDRATED


COMFORTABLE
HOT/DRY
HOT/WET
MEAN SKIN TEMPERATURE (°C)
40
38
36
34
32
30
28
PRE-
POST-
PRE-
POST-
PRE-
POST-
MEN
WOMEN
COMBINED
EUHYDRATED
HYPOHYDRATED


COMFORTABLE
HOT/DRY
HOT/WET
SWEAT RATE (g · m⁻² · h⁻¹)
600
400
200
0
PRE-
POST-
MEN
WOMEN
COMBINED
EUHYDRATED
HYPOHYDRATED



COMFORTABLE
HOT/DRY
HOT/WET
HEART RATE (b·min-1)
175
155
135
115
95
75
PRE-
POST-
MEN
WOMEN
COMBINED
EUHYDRATED
HYPOHYDRATED

1. The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documents.

2. Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: M38/82

2. GOVT ACCESSION NO.: AD-A118 669

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): Hypohydration and Exercise: Effects of Gender, Environment and Heat Acclimation.

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): Michael N. Sawka, Michael M. Toner, Ralph P. Francesconi, and Kent B. Pandolf

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Rsch Institute of Environment Medicine, Natick, MA 01760

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Project No. 3E162777A878

11. CONTROLLING OFFICE NAME AND ADDRESS: Same as 9

12. REPORT DATE: ~~11Aug 82~~ 19 July 82

13. NUMBER OF PAGES

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distrubution of this document is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Climate; dehydration; euhydration; heart rate; heat acclimatization; heat stress; mean skin temperature; plasma volume; rectal temperature; sex differences; sweat loss; temperature regulation.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this study was to examine the effects of heat acclimation and subject gender on treadmill exercise in a comfortable (20°C, 40% rh), a hot-dry (49°C, 20% rh) and a hot-wet (35°C, 79% rh) environment while subjects were hypo or euhydrated. Six males and six female subjects, matched for maximal aerobic power and percent body fat, attempted two exercise tests in each environment both before and after a 10-day heat acclimation program. One exercise test was attempted when euhydrated and the other test when hypohydrated

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(-50% from baseline body weight). In general, no significant ($P>0.05$) differences were noted between men and women at the completion of exercise for rectal temperature (T_{re}), mean skin temperature ($\bar{T}_{sk}$) or heart rate (HR) during any of the experimental conditions. Hypohydration was generally found to increase T_{re} and HR responses as well as to decrease sweat rate values while not altering $\bar{T}_{sk}$ responses. In the hypohydration experiments, heat acclimation significantly reduced T_{re} (0.19°C) and HR ($13 b \cdot min^{-1}$) responses in the comfortable environment, but reduced on HR responses in the hot-dry ($21 b \cdot min^{-1}$) and hot-wet ($21 b \cdot min^{-1}$) environments. The present findings indicate that men and women respond in a physiologically similar manner to hypohydration during exercise. It is also suggested that an expanded plasma volume, mediated by heat acclimation, may have attenuated T_{re} and HR responses during hypohydration.

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